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REORGANIZATION OF THE METEOROLOGICAL OFFICE

By THE DIRECTOR-GENERAL

A recent review of the functions and structure of the Meteorological Office revealed that the time had arrived for a number of changes in the Headquarters organization and these came into effect on 1 November 1966. The purpose of this note is to describe and explain these changes, which are aimed at producing a more functional structure better suited to current conditions in a period of rapid technological change. The introduction of the computer, satellites, facsimile techniques, etc., and the prospects of automatic methods of observation, data collection and processing are changing our operational methods and imposing greater centralization of forecasting services. We can also look forward to a major expansion of our research programme, to new developments in connexion with the World Weather Watch, and we must be responsive to the rapidly increasing demands for meteorological services. The reorganization takes cognizance of these trends and is also designed more specifically to :

- cater for the assimilation of computer products in the routine operations of the Central Forecasting Office ;
- produce a more logical structure in which each Branch has well-defined and integrated responsibilities with a minimum of overlapping between Branches ;
- ensure a more equitable distribution of the work load between Branches ;
- accommodate new Branches for Cloud Physics and Hydrometeorology, and a new long-range planning unit.

Changes in the Services Directorate.—Most of the changes have occurred in the Services Directorate where only the Data Processing Branch (Met.O.12) is unaffected. The responsibilities of the two Deputy Directors have been regrouped so that now one will be responsible for all the forecasting services, and the other will be responsible for the collection and processing of observational data and its application in climatology and allied fields.

The progress now reached in the operational use of computed forecast charts has encouraged the integration into Met.O.2 (Central Forecasting Office (CFO)) of that part of the former Met.O.8 (Forecasting Techniques) which was responsible for the development of computer programmes for operational forecasting. The construction of sea-ice charts, formerly the responsibility of the Marine Branch, will also be more closely integrated into the activities of CFO.

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Rapidly increasing commitments in hydrometeorology have imposed a heavy load on Met.O.3 (Climatological Services). This is being remedied by splitting off the rainfall organization from Met.O.3 and joining it with Agricultural Meteorology (formerly in Met.O.7) to form a new Met.O.8 (Agriculture and Hydrometeorology).

The former Met.O.5 (Observations and Communications) had a wide range of responsibilities but, in anticipation of major changes in meteorological communications and data-processing systems in the next few years, we think that this Branch should now concentrate on its telecommunications function. It has therefore been relieved of its responsibilities for Upper-air and CRDF Stations and for the Regional Servicing Organization, all of which now go to Met.O.16 (Instruments and Observations).

There is an important reallocation of functions between the former Met.O.6 (Aviation Services) and Met.O.7 (Public Services). Under the new scheme, all the responsibilities for the Defence Services, previously divided between Met.O.6, Met.O.7 and Met.O.17, are integrated into a Defence Services Branch (a new Met.O.6), while services for civil aviation will now be integrated with Public Services in a reconstituted Met.O.7. Met.O.7 thus loses army services and agrometeorology, and takes over civil aviation from Met.O.6 and the International Civil Aviation Organization affairs from Met.O.17.

The former Instrument Development Branch (Met.O.16) has now been transferred from the Research to the Services Directorate, where it also takes over technical control of the Upper-air Stations and responsibility for the CRDF Stations and the Regional Servicing Organization from Met.O.5. It is hoped that this move will bring the users and producers of instruments closer together and lead to more rapid development and acceptance of new instruments.

Met.O.17 (formerly Defence and International) loses its defence interests to Met.O.6, but will retain its responsibility for the World Meteorological Organization affairs and, in addition, will administer a new Planning Unit. Free of day-to-day problems, this Unit will be able to consider medium- and long-range developments likely to affect the Office as a whole ; for example, the World Weather Watch, automation, recruitment, training and manpower, demands for various services, cost/benefit studies, etc., and allow the Office to plan for at least five years ahead.

Changes in the Research Directorate.—A new Cloud Physics Branch has been established and comprises a laboratory physics group resulting from the transfer of my former department at the Imperial College of Science and Technology, a cloud dynamics group, and the radar unit based at the Royal Radar Establishment at Malvern. The new Branch replaces the former Met.O.15 (Atmospheric Physics) whose other responsibilities have been transferred to a strengthened Met.O.9 (Special Investigations). The Meteorological Research Flight, which is a facility serving the whole of the Office, will now report direct to the Deputy Director for Physical Research.

The only other change concerns research in local forecasting problems conducted largely at outstations. The responsibility for this, formerly with the old Met.O.8(*b*), now rests with Met.O.18 in the Research Directorate. This work, which I regard as very important, will be given every encouragement.

The new organization is summarized in Table I. Experience may revea the need for some further changes but it is important to give the new system time to settle down and work properly. Reorganizations are sometimes necessary and often beneficial but, to be fully effective, they should not occur too often.

TABLE I—NEW ORGANIZATION OF THE SERVICES AND RESEARCH BRANCHES

	DIRECTORATE OF SERVICES	
	DIRECTOR OF SERVICES	
DEPUTY DIRECTORATE (FORECASTING SERVICES)		D.D.Met.O.(F)
Met.O.2	Central Forecasting Office	A.D.Met.O(CF)
Met.O.5	Telecommunications	A.D.Met.O.(TC)
Met.O.6	Defence Services	A.D.Met.O.(DS)
Met.O.7	Public and Civil Aviation Services	A.D.Met.O.(PS)
DEPUTY DIRECTORATE (OBSERVATIONAL SERVICES)		D.D.Met.O.(O)
Met.O.1	Marine Branch	Marine Superintendent
Met.O.3	Climatological Services	A.D.Met.O.(CS)
Met.O.8	Agriculture and Hydrometeorology	A.D.Met.O.(AH)
Met.O.12	Data Processing	A.D.Met.O.(DP)
Met.O.16	Instruments and Observations	A.D.Met.O.(IO)
	DIRECTORATE OF RESEARCH	
	DIRECTOR OF RESEARCH	
DEPUTY DIRECTORATE (PHYSICAL RESEARCH)		D.D.Met.O.(P)
Met.O.14	Observatories and Micrometeorology	A.D.Met.O.(OM)
Met.O.15	Cloud Physics	A.D.Met.O.(CP)
Met.O.19	High Atmosphere	A.D.Met.O.(HA)
DEPUTY DIRECTORATE (DYNAMICAL RESEARCH)		D.D.Met.O.(D)
Met.O.9	Special Investigations	A.D.Met.O.(SI)
Met.O.11	Forecasting Research	A.D.Met.O.(FR)
Met.O.13	Synoptic Climatology	A.D.Met.O.(SC)
Met.O.18	Publications and Training	A.D.Met.O.(PT)
Met.O.20	Dynamical Climatology	A.D.Met.O.(DC)
	REPORTING TO DIRECTOR-GENERAL	
Met.O.17	International and Planning	A.D.Met.O.(IP)

RETIREMENT OF MR B. C. V. ODDIE

Mr B. C. V. Oddie retired from the Meteorological Office on 25 October 1966 after nearly 40 years' service. Since 1959 he had been a Deputy Director of the Office, responsible for a wide range of functions covering the provision of meteorological services.

After graduating from Queen Mary College, London University, with first class honours in physics, Mr Oddie entered the Meteorological Office in December 1926 and joined the group at Cardington which was then in the forefront of meteorological research in connexion with the airship development programme. This work came to an end in 1930 when the R101 disaster occurred but the results, which were published in *Geophysical Memoirs* No. 54—The Structure of Wind over Level Country—have had a lasting value in micrometeorology.

Mr Oddie's next posting was to Lerwick Observatory for three years and then he became involved in forecasting and held various posts at home and overseas until, in 1955, he returned to research as Assistant Director responsible for physical research. In this field he quickly established a wide reputation in

atmospheric chemistry and subsequently there have been many who have been glad to acknowledge the value of the realistic opinions he expressed upon the subject of rain making. Promotion to Deputy Director in 1959 brought him once again into the services field and in the following six years he was closely associated with many important developments, including the planning and installation of the high-speed computer COMET.

Mr Oddie has the unusual distinction of earning an international reputation in two fields, first in athletics and then in meteorology. He won the national championship for the mile and represented England in many international matches, notably in the 1928 Olympic Games when in the 5000 metres event he ran against the legendary Nurmi of Finland.

A keen supporter of the Royal Meteorological Society, Mr Oddie was Honorary Treasurer from 1958 to 1964. In 1965 his outstanding services in the Meteorological Office were recognized when he was appointed a Commander of the Order of the British Empire. His colleagues will remember him for his independence of thought and his scientific integrity—his opinions were shrewd and penetrating and expressed with a delightful humour. He has retired with the good wishes of a host of friends.

P. J. MEADE

551.509.314:551.509.324.2:551.557.5:551.577.37

THE JET STREAM AT 500 MB AS A PREDICTOR OF HEAVY RAIN

By G. R. R. BENWELL

Summary.—The possibility of using certain 500 mb jet-stream characteristics for handling the forecasting of heavy rainfall arose from a synoptic research investigation which was carried out to find criteria for forecasting heavy falls of rain, somewhat comparable to the heavy falls specially listed in *British Rainfall.* A test showed that the areas specified by the criteria based on the 500 mb chart can be expected to receive some intense rain but that the rain may not be sufficiently prolonged to give heavy falls.

Introduction.—It would obviously be very useful if criteria were available for forecasting with some confidence the occurrence of heavy rainfall in the British Isles. In *British Rainfall,*[1] under the chapter heading 'Heavy falls on rainfall days', are listed those occasions each year (*a*) when there were falls of rain of 2·5 inches or more and (*b*) when there were falls of at least 7·5 per cent of the total annual rainfall. It was decided that an examination of these occasions should be made to obtain the required criteria.

The geographical and seasonal distribution of heavy falls on rainfall days.—The occasions examined were those listed for the years 1946–57 inclusive, in *British Rainfall* ; there were 533 such days in these 12 years, with the individual annual totals ranging from 36 days in 1952 to 57 days in 1957. The distribution throughout the year is shown in Table I, which lists for each month the average number of days with heavy falls. It will be noted that the greatest numbers occur in the summer months July, August and September and that there is another maximum in December. To examine the regional

TABLE I—AVERAGE MONTHLY NUMBER OF DAYS WITH HEAVY FALLS (1946–57)

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Average	3·9	1·9	2·1	1·7	1·5	3·7	6·3	6·3	5·7	3·5	3·6	4·3

variation the United Kingdom was split into 12 areas I to XII, as shown in Figure 1 and the geographical distribution of the heavy falls is shown in Table II ; the half-yearly totals for summer and winter are given for each area in addition to the monthly totals. The important features of this table are that whereas in southern and eastern districts of Britain the highest monthly totals of heavy falls are those for the summer months of July and August, in north-western districts the highest monthly totals occur in the winter season, although a fairly large number of heavy falls occurs also in the summer season. In contrast in south-eastern districts very few heavy falls occur in the winter months of November to April (3 per cent in area I and 6 per cent in area II).

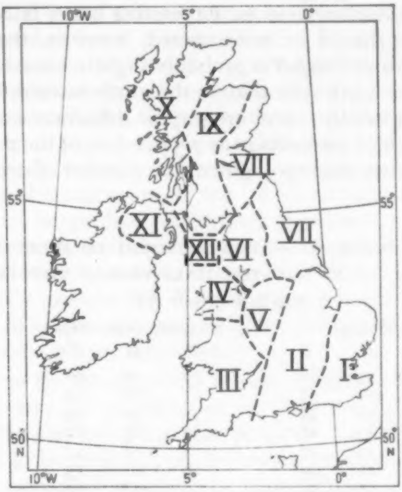

FIGURE 1—THE TWELVE AREAS OF THE UNITED KINGDOM USED IN TABLE II

TABLE II—TOTAL NUMBER OF DAYS WITH HEAVY FALLS FOR EACH AREA, WITH MONTHLY AND HALF-YEARLY (SUMMER AND WINTER) TOTALS (1946–57)

Area*	Number of days	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Summer Apr.–Sept.	Winter Oct.–Mar.
I	74	0	0	1	0	8	10	26	16	5	6	1	0	66	8
II	75	1	0	1	0	6	16	20	12	10	7	1	1	64	11
III	125	8	8	9	4	5	8	15	21	14	12	13	8	67	58
IV	135	20	9	13	4	1	9	17	11	17	11	10	13	59	76
V	36	1	1	0	0	1	4	15	9	3	2	0	0	32	4
VI	107	12	2	3	5	1	5	10	11	14	11	19	14	46	61
VII	63	3	3	4	3	4	6	11	15	5	4	2	3	44	19
VIII	27	0	0	1	0	0	2	7	7	4	2	2	2	20	7
IX	80	9	4	5	2	1	5	10	10	8	7	6	13	36	44
X	141	17	11	7	10	1	4	9	9	22	17	11	23	55	86
XI	12	1	0	1	0	1	1	3	2	0	2	0	1	7	5
XII	7	0	0	1	0	0	0	1	2	1	1	0	1	4	3

*Areas I–XII are shown in Figure 1.

From the synoptic notes made during the examination it was found possible to classify these occasions with heavy falls under the following broad categories :

F rain of frontal character,

D rain associated with depressions,

and *T* rain of a showery or thundery character.

The classification is a little subjective and as the categories are not mutually exclusive some occasions were entered in more than one category. Table III shows the total number of occasions listed in each category for each of the areas I to X, as well as the numbers for the summer and winter half-years : areas XI and XII were omitted from this analysis as the numbers of occasions in these areas were very small. Table III confirms that in south-eastern districts (areas I and II), the thundery type of heavy fall is predominant, especially in summer, whilst in north-western districts (areas IV, VI and X) the heavy falls, especially in winter, are more often associated with fronts. It is therefore possible that the predictors required for the objective forecasting of heavy falls of rain in one part of Britain during one season of the year will not be the same as those required for forecasting heavy falls in other areas and at other seasons. It should be remembered, however, that the definition of heavy fall used in *British Rainfall* is probably slightly biased towards producing more occasions in the north-west than in the south-east since a fall of 2·5 inches in the north-west, especially where orographic influences are pronounced, does not represent such a high percentage as 7·5 per cent of the total annual rainfall, the alternative criterion used to augment the number of occasions listed in the south-east district.

TABLE III—TOTAL NUMBER OF DAYS ACCORDING TO SELECTED SYNOPTIC CATEGORIES* FOR AREAS I TO X, AND THE HALF-YEARLY TOTALS FOR SUMMER AND WINTER (1946–57)

Area	All days			Summer (Apr.–Sept.)			Winter (Oct.–Mar.)		
	F	*D*	*T*	*F*	*D*	*T*	*F*	*D*	*T*
I	21	34	61	16	30	60	5	4	1
II	25	38	53	17	32	52	8	6	1
III	75	51	42	23	35	34	52	16	8
IV	101	45	18	32	25	12	69	20	6
V	10	19	27	7	18	27	3	1	0
VI	65	41	29	19	21	15	46	20	14
VII	26	37	24	9	28	22	17	9	2
VIII	8	23	7	4	16	7	4	7	0
IX	47	36	20	10	25	14	37	11	6
X	104	34	35	23	16	14	81	18	21

* *F* indicates rain associated mainly with fronts
D indicates rain associated mainly with depressions
T indicates rain associated mainly with thunderstorms/heavy showers
Areas I–X are shown in Figure 1.

Determination of the criteria for use as predictors of heavy rain.—To examine more closely the type of heavy rainfall associated with frontal systems, a reasonably homogeneous set of occasions was obtained by choosing from among the frontal occasions those dates when, additionally, there was substantial rain over a considerable area (several counties) ; 63 occasions selected in this way provided the basic data from which it was hoped to obtain discriminating predictors for forecasting purposes. The predictors examined were those normally available to the forecasters and care was taken to include sufficient predictors to ensure that the vertical-motion and moisture fields involved in the rain process would be adequately represented. The numerically computed mean vertical motions over the 1000–600 mb and 600–200 mb layers were not used. Although such vertical-motion calculations are now being made available operationally they were not available for the occasions studied in

this investigation ; furthermore, there is little reason to suppose that numerically computed vertical motions, based on a grid length of approximately 160 n.miles, represent the scale on which heavy rainfall occurs any better than the more familiar synoptic predictors (e.g. Knighting *et alii*[2]). Considerable attention was directed to the upper air charts at 700, 500 and 300 mb. The following characteristics were examined in relation to the area affected by the heavy fall of rain ; the position and orientation at these levels of the belts of wind maxima (hereafter referred to as 'jets') ; the positions of the left exits of the jets ; whether the jets were undergoing lateral shift and/or extending: and whether the jets were cyclonically or anticyclonically curved or had a sinusoidal pattern. Other predictors relating to the stability and water content of the air masses involved in the rain process, as well as surface predictors such as minimum pressure and pressure tendency during the 24-hour period over the heavy rain area, were among the predictors examined. From among the common features of these heavy falls it was found that a large proportion of the 63 occasions was associated with the approach of south-west to west jet streams, or with the movement of small perturbations along such jets, but that there was only a slight bias towards cyclonic curvature. Apart from one or two exceptions the wet-bulb potential temperature of the warm air mass involved in the rain process increased with height from the surface to 500 mb and the water content of the warm air was mostly well above the monthly normal. Among the surface predictors it was found that on most occasions there was, during the 24-hour period, a three-hourly pressure fall of at least 2·5 mb with usually a sustained fall of pressure of 8 mb or more and the highest dew-point in the warm air was 6 degF or more above the monthly normal.

Up to this point in the investigation a large number of potential predictors had been retained and the question as to what number of predictors was desirable statistically for handling this problem had been left unresolved. Some restraint had to be imposed, partly because meteorological elements are often very highly correlated resulting in considerable duplication when the number of predictors becomes very large. Some simplification therefore seemed necessary and would in any case probably be welcomed by practising forecasters. Of the potential predictors, those based upon the 500 mb flow seemed the most promising since (i) unlike some of the others, e.g. surface dew-point or 700 mb dew-point depression, they are not greatly affected by the occurrence of rain, (ii) they are more easily predictable than most others (the prediction of 500 mb charts objectively by computer has now reached an acceptable standard) and (iii), as inferred in (ii), there is less subjectivity in using these predictors than arises, say, in the use of predictors linked with conventional surface analyses of frontal systems.

From a consideration of the 500 mb features of the heavy falls, criteria favourable for the occurrence of heavy rain over an area would seem to be as follows :

(i) the existence of a jet stream of 70 knots or more at 500 mb from a direction between 220° and 290°,

with, in addition, the requirement that

(ii) the left exit of the jet stream (as defined by the 70-knot isotachs) should be over the area, or

(iii) a perturbation of the jet stream should be close to this area.

These 'favourable' 500 mb criteria are shown diagrammatically in Figure 2, (*a*) giving the dimensions of the area which is subject to heavy rain occurrence near the left exit of the jet stream and 2 (*b*) giving the dimensions of the area which is considered liable to heavy rain near the perturbation of the jet stream. On reflection it will be apparent that if these 500 mb criteria are satisfied then some of the other common features of these particular heavy falls will also be present. For example : the existence of the strong wind belt at 500 mb implies also the existence of a strong baroclinic zone and frontal system on most occasions ; the orientation of this jet stream about a west-south-west direction carries the implication that the warm air mass to the south of the jet stream has been drawn from a more southerly latitude over the Atlantic and therefore it is probable that the necessary stability and water content features of the warm air will be represented. Use of these 500 mb criteria, given in Figure 2, in conjunction with actual and forecast 500 mb charts enables the forecaster to demarcate areas of heavy rain and the probable track of these areas. The likelihood of any particular part of Britain receiving heavy rain can then be determined.

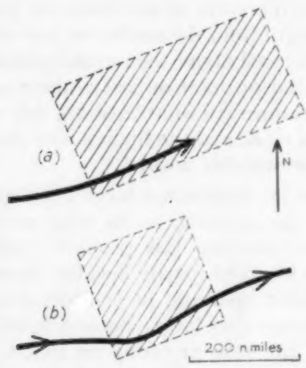

FIGURE 2—500 MB CRITERIA SHOWING THE POSITION AND ORIENTATION OF THE AXIS OF THE 500 MB JET STREAM IN RELATION TO THE AREAS OF HEAVY RAIN

(*a*) Near jet-stream exit (beyond the arrow head wind speeds become less than 70 knots).

(*b*) Near perturbation of jet stream.
Areas of heavy rain are shaded.

Test of the 500 mb criteria as predictors of heavy rain.—A test was carried out to determine how successful the use of these criteria would be in practice for forecasting heavy rain on a scale comparable with that of the *Daily Weather Report* (*DWR*) station network. Such a network would not necessarily pick up the same occasions as those covered by the *British Rainfall* definition but some similarity would be expected. Great Britain was divided (Figure 3) into four regions : Scotland, the northern districts of England and Wales, the south-eastern districts of England and south-western districts of England with South Wales. The 500 mb working charts of the Central Forecasting Office for the five years 1953–57 were scrutinized and all those

FIGURE 3—BOUNDARIES OF THE FOUR REGIONS USED IN THE TEST OF THE CRITERIA

occasions were selected when a 500 mb jet stream of 70 knots or more, from a direction between 220° and 290° approached, crossed, or passed within 200 n. miles of the British Isles.

Those regions were listed which were considered liable to receive heavy rain using the criteria in the way indicated in Figure 2. From these entries a catalogue was constructed showing on which rain days and for which regions heavy rain was indicated. All those days which had appeared in the *British Rainfall* list of 'Heavy falls on rainfall days' were then removed as these could not be regarded as independent.

The next problem was to decide whether, in the event, these regions had been subjected to heavy rain and after some consideration it was decided that heavy rain could be presumed to have fallen in a region if one of the *DWR* stations located in that region

(*a*) recorded rain of heavy intensity in the past weather reported by the Beaufort letters

or (*b*) recorded 10 mm or more of rain in either of the two 12-hour periods which constituted the rain day.

The two alternatives were regarded as separate definitions of heavy rain and for easy reference are referred to as definitions (*a*) and (*b*). The results of the test using these two definitions are shown in Table IV : it will be seen at once that the two definitions represent different aspects of the heavy rain problem. Definition (*a*) results in a higher frequency of heavy rain occurrence than definition (*b*), much as might have been expected. The percentage of 'forecasts' of heavy rain which were correct is higher when definition (*a*) is used but this may be partly explained by the higher frequency already noted. However, it

TABLE IV—EXPECTATION OF HEAVY RAIN COMPARED WITH OCCURRENCES AS DEFINED BY ALTERNATIVE DEFINITIONS (*a*) AND (*b*)* (1953–57)

	Scotland	N. England	S.W. England	S.E. England
1. Number of days on which forecast criteria were satisfied	225	158	130	127
2. Using definition (*a*)*				
(i) Number of forecasts correct †	140	103	92	97
(ii) Percentage of forecasts correct	62	65	71	76
(iii) Total number of days with heavy rain	567	454	438	507
(iv) Correct forecasts as a percentage of the total number of days with heavy rain	25	23	21	19
3. Using definition (*b*)*				
(i) Number of forecasts correct †	87	60	49	35
(ii) Percentage of forecasts correct	39	38	38	27
(iii) Total number of days with heavy rain	338	206	219	174
(iv) Correct forecasts as a percentage of the total number of days with heavy rain	26	29	22	20

* See definitions on page 9

† Predictors were chosen by examining occasions of frontal rain but entries in 2(iii) and 3(iii) include heavy falls associated with depressions and thunderstorms as well.

will be seen that the proportion of the total number of occasions with heavy rain which were successfully 'forecast' is much the same whichever definition is used, ranging from about one in four in the north to one in five in the south. As a point of interest, it should perhaps be mentioned that a small improvement in the success rate can be achieved in this test if, in addition, criteria for certain surface parameters are also required to be satisfied : it should be emphasized that if this refinement is introduced, the numbers of correct forecasts for each region fall. (However, this is the dilemma which has to be faced in weather forecasting : if a forecast of a specific event is required to have a very high chance of success, then the use of only one set of criteria developed for forecasting this event to the required level will probably only select a small proportion of the actual occurrences.)

Conclusions.—From a study of a large number of occasions listed in *British Rainfall* as heavy falls on rainfall days it was found possible to formulate criteria, based on certain 500 mb jet-stream characteristics, which could be used as predictors of heavy rain. A test which was carried out using the 5-year period 1953–57 showed that although the areas specified by these 500 mb criteria can be expected, fairly confidently, to experience some intense rain, yet there is less than a 50 per cent chance that the rain will be sufficiently prolonged to give heavy falls on a scale which can be observed by the *DWR* station network. The use of such criteria must therefore be somewhat restricted but may prove of interest to forecasters.

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2. KNIGHTING, E. *et alii* ; An experiment in numerical forecasting. *Scient. Pap. met. Off., London*, No. 5, 1961.

551.501.45:551.577.36(595)

PROBABLE MAXIMUM 24-HOUR PRECIPITATION OVER MALAYA BY STATISTICAL METHODS

By J. G. LOCKWOOD, Ph.D.
University of Leeds

Summary.—The probable maximum 24-hour precipitation (PMP) is described for Malaya after a brief discussion of the rainfall data available. Established statistical procedures are used to obtain estimates of the maximum precipitation likely within various periods of time as well as estimates of PMP, the largest rainfall ever likely to be experienced. Estimates of maximum areal rainfall may be obtained by using a U.S. Weather Bureau hurricane model.

There is a general tendency for maximum daily precipitation to be highest on the east coast and to decrease westwards. Results from the mountainous regions are inconclusive but it appears that heavy rainfalls are more likely to occur over steep mountain slopes or in narrow valleys rather than over interior plateaux.

Introduction.—The highest rainfall meteorologically possible for a given duration over a specific area is called the probable maximum precipitation (PMP). Estimates of PMP are of more than academic interest. Important hydrological structures are normally designed to withstand all floods up to a maximum value which has a reasonably small probability of occurrence in the area. This probability is reflected in the length of the 'return period' of the maximum flood considered. The return period of the flood is the average number of years which must elapse before the magnitude of the flood will be equalled or exceeded. An important costly dam will normally be constructed to withstand floods with extremely long return periods. Small unimportant structures such as irrigation channels may be built to withstand floods with only short return periods.

Flood estimates have been made for isolated hydrological projects in Malaysia but the country has a large variety of hydrological structures and there is therefore a need for estimates of the return periods of a wide range of floods in various parts of Malaysia. There are dams for hydroelectric power and irrigation, reservoirs for drinking water, deep pools for tin dredges, and irrigation and drainage channels. Most urban areas are drained by a network of deep open ditches lined with concrete. Attention should also be paid to floods affecting derelict ponds, fish ponds and even the flooded paddy fields.

Floods can be estimated from river flow records but these are often inadequate for estimating flood magnitudes with a long return period and long rainfall records may be more satisfactory for this purpose. It is possible to estimate flood magnitudes from rainfall data by using modern, river flow theory. There is therefore a need for maximum precipitation estimates and this paper describes an investigation into various estimates of maximum rainfall in many parts of Malaya.*

There are two general methods of estimating PMP values : by statistical procedures and by storm maximization techniques. The statistical procedures make use of the statistical theory of extreme values. Unfortunately such theory assumes that there is a long rainfall record giving a good sample of the storm experience of the area. Even in the highly developed countries this is unlikely ; therefore for very long return periods the maximum precipitation estimates by statistical procedures must be treated with reserve. Nevertheless, statistical procedures are probably the best method of making estimates for short return periods. Most workers consider that maximum precipitation estimates for extremely long return periods are best made by the storm maximization tech-

*Also known as West Malaysia. East Malaysia comprises Sarawak and Sabah.

niques. Storm maximization consists of estimating, from a study of the basic physics of the atmosphere, the greatest precipitation that is likely to fall. The technique is described fully elsewhere.[1,2,3] The storm maximization technique has been used in Malaysia for several isolated dam building projects but, because the physics of the equatorial atmosphere is poorly understood, it has not been applied to the whole country.

Malaya lies near to the equator and rainfall mainly comes from weak disturbances in the equatorial trough, but the area lies on the equatorial side of the typhoon zone and typhoons are not known to have moved further south than southern Thailand.[4] Thus Malaya is a tropical area in which it is not necessary to consider typhoons in PMP estimations except perhaps in the extreme north.

Data.—The locations of rain-gauges used in the investigation are shown in Figure 1. The number of rain-gauges in each state from which observations were used is tabulated in Table I. Table I also indicates, for each state, the

TABLE I—NUMBER OF RAIN-GAUGES PER STATE AND NUMBER OF GAUGES HAVING RECORDS WITH LENGTHS WITHIN SELECTED LIMITS

State	Number of gauges having records with lengths within selected limits						Total number of gauges per state
	Length of record in years						
	15–19	20–29	30–39	40–49	50–59	60–69	
	number of gauges						
Johore	27	4					31
Kedah			3	3			6
Kelantan	10	1					11
Malacca	7						7
Negri Sembilan			4	9			13
Pahang	12	5	6	4	4		31
Penang		1					1
Perak			3	25	12	3	43
Perlis							
Province Wellesley							
Selangor			3	22	9	1	35
Trengganu	7	1					8
Total							186

All stations have a break in records during the period 1940 to 1945. This break is not included in the number of years of record.

number of gauges having records with lengths within selected limits. Most of the population live on the western side of Malaya and the settled areas have a reasonable rain-gauge network. The interior has a sparse network of gauges because it consists of almost uninhabited mountains and jungle. The mountainous areas of the country are of interest, despite the low density of population, because they contain the sources of many of the major rivers.

The situation regarding rainfall records for Malaya is very unsatisfactory.[5] Most of the original pre-1940 records were lost during the war with Japan and only monthly summaries remain for this period. The monthly summaries contain notes on the largest daily rainfalls in each month. No records exist for the period 1940–45 because of the Japanese war (1941–45), therefore complete daily rainfall records exist for only the last 20 years. Because of the unsatisfactory state of the rainfall records it is only possible to consider extreme rainfalls for a 24-hour period. Data do not exist for a full-scale investigation into extreme rainfalls for periods of more than or less than one day.

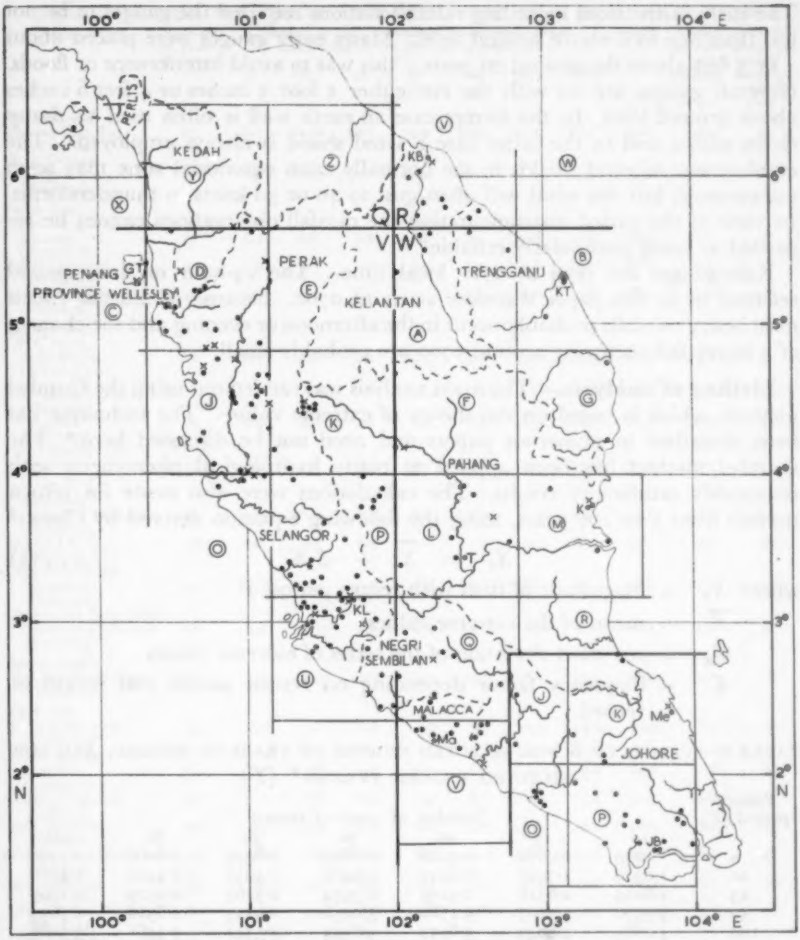

FIGURE 1—LOCATION OF RAIN-GAUGES USED IN INVESTIGATION IN MALAYA

Stations listed in Table III are marked by crosses. A grid is superimposed which may be used to identify stations listed in Table III.

Major towns

GT	**Georgetown**	**Me**	**Mersing**
I	**Ipoh**	**K**	**Kuantan**
KL	**Kuala Lumpur**	**KT**	**Kuala Trengganu**
Ma	**Malacca**	**KB**	**Kota Bahru**
JB	**Johore Bahru**	**T**	**Temerloh**

Prior to the Japanese war, most rainfall stations were equipped with copper rain-gauges either 8 inches or 5 inches in diameter, and glass measuring cylinders. Immediately after the Japanese war, equipment was difficult to obtain and locally made galvanized-iron rain-gauges were used, 8 inches in diameter, with metal measuring cylinders and dipsticks. This equipment was gradually replaced by standard 8-inch diameter gauges with glass measuring cylinders.

The early instructions regarding rainfall stations required the gauges to be not less than one foot above ground level. Many early gauges were placed about 4 or 5 feet above the ground on posts ; this was to avoid interference or floods. Now all gauges are set with the rim either 1 foot 3 inches or 4 feet 6 inches above ground level. In the former case an earth wall is often used to damp down eddies and in the latter case a wind shield is always employed. The employment of wind shields in the normally calm equatorial zone may seem unnecessary, but the wind will often gust to 40 or 50 knots in thunderstorms. In view of the varied instrumentation the rainfall observations cannot be regarded as being particularly reliable.

Rain-gauges are read at 0700 local time. The 24-hour or daily period referred to in this paper therefore starts at 0700. Because of diurnal effects most heavy rainfalls probably occur in the afternoon or evening and the chances of a heavy fall occurring around 0700 are probably small.

Method of analysis.—The main analysis was carried out using the Gumbel method, which is based on the theory of extreme values. The technique has been described in numerous papers and need not be discussed here.[6] The Gumbel method has been applied to many hydrological phenomena with reasonably satisfactory results. The calculations were also made for return periods from 5 to 100 years, using the following equation derived by Chow:[7]

$$X_T = \overline{X} + S_x K \qquad \ldots (1)$$

where X_T = magnitude of item with return period T

$\overline{X}$ = mean of the extreme values

S_x = standard deviation of the series of extreme values

K = frequency factor depending on return period and length of record.

TABLE II—VALUES OF K FOR SELECTED NUMBER OF YEARS OF RECORD, AND FOR SELECTED RETURN PERIODS* (T)

Return period (T)	Number of years of record 10	15	20	30	40	60	100
5	1·0479	0·9672	0·9186	0·8663	0·8379	0·8068	0·7790
10	1·8319	1·7026	1·6247	1·5410	1·4955	1·4457	1·4010
25	2·8224	2·6316	2·5169	2·3934	2·3263	2·2529	2·1869
50	3·5570	3·3207	3·1786	3·0256	2·9425	2·8516	2·7699
100	4·2865	4·0049	3·8357	3·6534	3·5544	3·4461	3·3486

*After Weiss[8]

The values of K used are given in Table II, which is taken from Weiss.[8] The values calculated by the two methods agreed closely and for organizations without an electronic computer the second method provides an easy means of calculating maximum precipitations.

Discussion of results.—Maximum precipitation values for 24 hours were calculated using the Gumbel method for return periods of 5, 10, 25, 100, 1000 and 10,000 years. The results were plotted on charts and isopleths drawn. Figures 2 and 3 are charts for return periods of 10 and 100 years ; values for various return periods at selected stations are also tabulated in Table III. Reasonable isopleth patterns were easily constructed for the west coast states, but because of the sparsity of observations there was some doubt as to the exact placing of the isopleths over the central and eastern parts of Malaya. The

TABLE III—MAXIMUM 24-HOUR POINT PRECIPITATION AT SELECTED STATIONS

Station name	Number of years of record	Maximum daily rainfall estimated by Gumbel method for return periods, in years, of							PMP*	Greatest observed fall with estimated return period	
		5	10	25	50	100	1000	10,000		Rainfall	Return period
		inches								*inches*	*years*
Johore State											
Mersing Met. Stn (K827485)†	27	8.7	10.5	12.7	14.3	15.9	21.2	26.5	44.6	14.0	44
Muar General Hospital (V702652)	27	6.3	7.5	8.9	10.0	11.0	14.5	17.9	29.7	10.0	50
Kedah State											
Pulau Langkawi Hospital (X397818)	37	5.2	6.2	7.5	8.4	9.4	12.5	15.6	26.8	8.1	40
Baling Hospital (Y686033)	45	4.9	5.7	6.7	7.5	8.3	10.8	13.3	22.8	7.4	46
Kulim Hospital (D254656)	42	6.0	6.9	8.2	9.1	9.9	12.9	15.8	26.7	10.5	158
Kelantan State											
J.P.T. Store, Kota Bharu (RV311549)	26	8.7	10.2	12.0	13.3	14.6	19.0	23.3	38.0	13.0	44
Negri Sembilan State											
Kuala Pilah Hospital (Q303473)	49	4.4	5.0	5.7	6.2	6.8	8.5	10.2	16.8	6.0	37
Port Dickson Hospital (U747221)	48	5.9	7.0	8.4	9.5	10.6	14.1	17.6	30.8	12.7	411
Pahang State											
Kuala Lipis Hospital (F069223)	55	5.3	6.2	7.3	8.1	9.0	11.7	14.4	24.8	10.3	312
Maran J.K.R. (WL940493)	46	6.1	7.3	8.9	10.1	11.2	15.1	18.9	33.2	9.7	40
Lian Hup Estate (Kuantan) (M585795)	45	10.7	12.9	15.7	17.7	19.8	26.6	33.4	58.9	24.0	412
Quarry Rd, Brinchang, Cameron Highlands (K258594)	31	3.3	3.7	4.1	4.5	4.8	6.0	7.1	11.1	4.5	50
Penang Island											
Met. Stn Bayan Lepas (C906572)	22	7.5	9.0	10.9	12.3	13.7	18.4	23.0	38.0	10.1	17
Perak State											
Taiping Hospital (D482019)	57	6.3	7.1	8.2	9.0	9.8	12.4	14.9	25.0	8.7	41
Kuala Kangsar Hospital (J714939)	59	4.2	4.8	5.5	6.0	6.5	8.2	9.9	16.4	5.8	37
Gopeng Hospital (J988573)	59	5.1	5.8	6.7	7.4	8.0	10.3	12.5	21.1	9.6	500
Ipoh Hospital (J896730)	54	4.4	5.0	5.7	6.2	6.7	8.5	10.2	16.9	7.0	141
Telok Anson Hospital (J812036)	59	4.8	5.3	6.0	6.6	7.1	8.8	10.5	17.1	6.5	46
Grik Hospital (D947727)	57	5.1	5.9	6.9	7.7	8.4	10.9	13.4	22.9	7.7	50
Maxwell Hill, Taiping (D537044)	60	6.6	7.4	8.3	9.1	9.8	12.1	14.4	23.5	9.7	95
Cicely Estate Telok Anson (O860992)	46	5.6	6.6	8.0	9.0	10.0	13.1	16.4	28.5	12.9	822
Trong Rubber Estate (J449866)	45	6.8	8.4	10.4	11.8	13.3	17.9	22.6	40.3	18.8	1520
Selangor State											
General Hospital, Kuala Lumpur (U636997)	52	4.2	4.8	5.5	6.0	6.6	8.3	10.0	16.6	6.4	80
Tanglin Hospital, Kuala Lumpur (U624968)	55	4.5	5.1	6.0	6.6	7.2	9.3	11.3	19.2	8.7	500
Kajang Hospital (U747789)	56	4.4	5.0	5.6	6.1	6.6	8.2	9.7	15.8	6.4	83
Midlands Estate, Klang (U381869)	44	4.9	5.6	6.5	7.1	7.7	9.9	12.0	19.9	6.9	42
Trengganu State											
Met. Stn, Kuala Trengganu (WB377608)	25	10.1	12.3	14.9	16.9	18.8	25.3	31.7	53.1	18.5	90

*Estimated from equation (1) with $K = 15$. †Grid reference.
Stations are marked on Figure 1 by crosses and may be identified by reference to the grid.
All stations have a break in records during the period 1940 to 1945. This break is not included in the number of years of record.

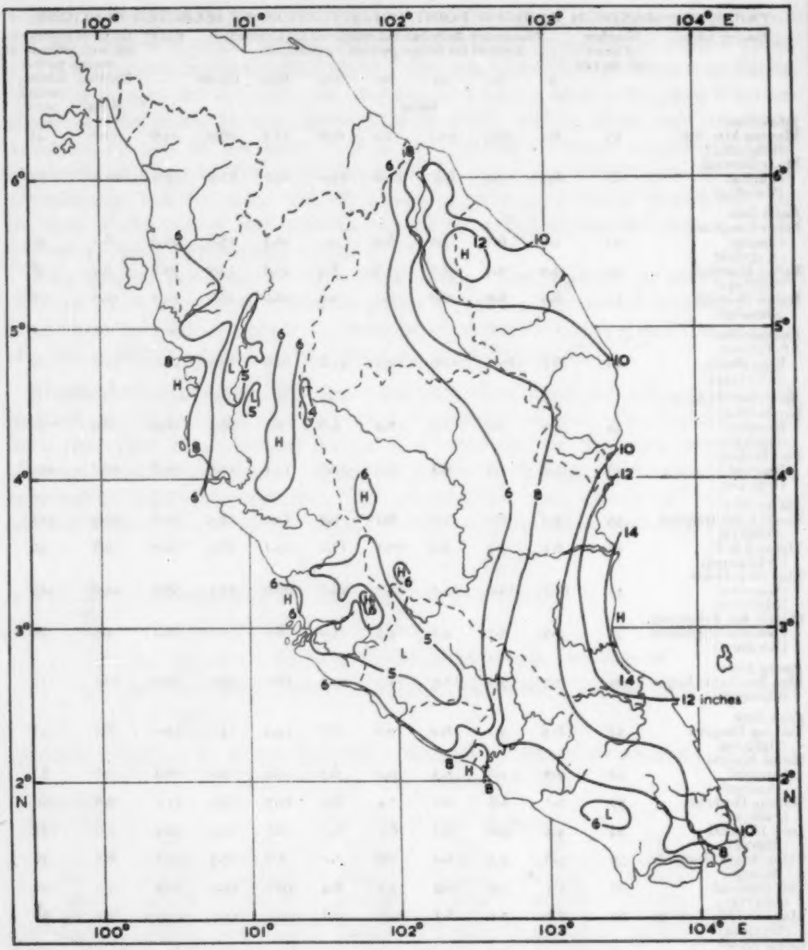

FIGURE 2—PROBABLE MAXIMUM 24-HOUR POINT PRECIPITATION FOR A RETURN PERIOD OF 10 YEARS

Isopleths are drawn using the network shown in Figure 1 and therefore are estimated over certain areas.

values for return periods of 100 years and less are considered to be realistic estimates of the maximum falls likely during the given return periods. The values for return periods of 1000 and 10,000 years are considered to represent estimates of the upper limits of daily rainfall, but these estimates should be used with caution. Extreme daily rainfalls with return periods exceeding 100 years have been recorded by 20 per cent of the rain-gauges. Four gauges, included in Table III, have recorded falls with return periods exceeding 500 years.

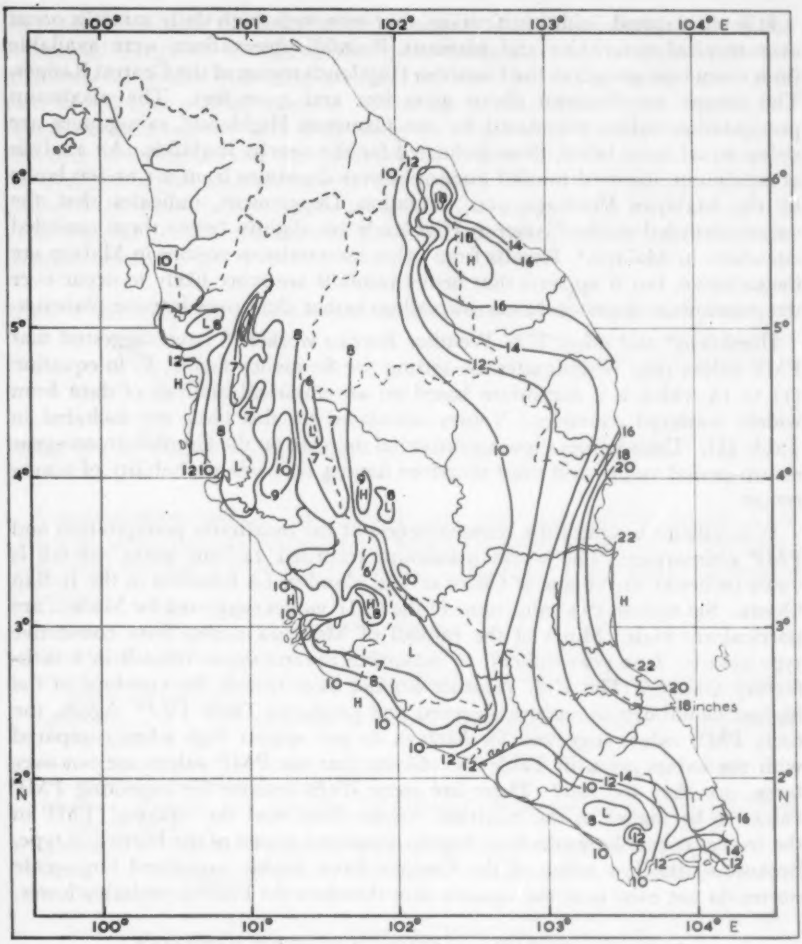

FIGURE 3—PROBABLE MAXIMUM 24-HOUR POINT PRECIPITATION FOR A RETURN PERIOD OF 100 YEARS

Isopleths are drawn using the network shown in Figure 1 and therefore are estimated over certain areas.

The distribution of maximum precipitation estimates is clearly partly determined by the general relief. There is a general tendency for maximum precipitation to be highest on the east coast and to decrease westwards. The east coast is known to receive heavy rainfall during surges in the north-east monsoon. Even in the west, maximum precipitation tends to be highest along the coast and to decrease inland, before rising again in the mountainous interior.

It is often stated, with justification, that extremely high daily rainfalls occur over tropical mountains and plateaux. Rainfall observations were available from seven rain-gauges in the Cameron Highlands region of the Central Ranges. The gauges are between about 3500 feet and 5500 feet. The maximum precipitation values calculated for the Cameron Highlands' rain-gauges are either equal to or below those indicated for the nearby lowlands. An analysis of maximum observed rainfall intensities over durations from 0.1 to 100 hours by the Malayan Drainage and Irrigation Department, indicates that the values recorded in the Cameron Highlands are slightly below those recorded elsewhere in Malaya.[5] Results from other mountainous regions in Malaya are inconclusive, but it appears that heavy rainfalls are more likely to occur over steep mountain slopes or in narrow valleys rather than over interior plateaux.

Hershfield[9] and other U.S. Weather Bureau workers[10] have suggested that PMP values may be estimated by setting the frequency factor, K, in equation (1) to 15 which is a maximum based on an empirical analysis of data from widely scattered countries. Values calculated on this basis are included in Table III. These values show a substantial increase on the Gumbel 10,000-year return-period values and must therefore have a very low probability of occurrence.

It is difficult to check the reasonableness of the maximum precipitation and PMP estimations. The world maximum recorded 24-hour point rainfall is 73·62 inches at the village of Cilaos on the island of La Réunion in the Indian Ocean. Set against this value none of the PMP values suggested for Malaya are particularly high. Much of the rainfall of Malaysia comes from convective type clouds. It is very difficult to maximize thunderstorm rainfall in a satisfactory manner. The U.S. Weather Bureau have drawn the envelope of the highest cloudburst intensities observed and produced Table IV.[10] Again, the daily PMP values suggested for Malaya do not appear high when compared with the values given in Table IV. Given that the PMP values are not over large, are they too low? There are some slight reasons for expecting PMP values to be higher in the maritime tropics than near the equator. PMP in the tropics normally results from highly organized storms of the hurricane type. Because of the low value of the Coriolis force, highly organized large-scale storms do not exist near the equator and therefore the PMP is probably lower.

TABLE IV—PROBABLE MAXIMUM CLOUDBURST RAINFALL*

Duration *hours*	Amount *inches*
1	15·3
2	21·4
3	26·1
4	30·0
5	33·5
6	36·6

*After U.S. Weather Bureau Technical Paper No. 42.[10]

The maximum precipitation values suggested are for points ; areal rainfalls are of more interest to hydrologists. Much of the normal rainfall of Malaysia comes from convective clouds and it is a well-known property of these storms that rainfall decreases rapidly with distance from the centre of the storm. The Malayan Drainage and Irrigation Department have analysed four storms

and found this to be the case.[5] On the other hand, synoptic experience in the equatorial trough zone indicates that intense rain is often associated with weak disturbances in the equatorial trough and that these disturbances can cause rain to fall over extensive areas. Maximum areal rainfalls may therefore be derived from Figures 2 and 3 by using the depth–area relationship based on the U.S. Weather Bureau hurricane model (Table V),[10] though it may result in overestimations because storms like those of the model do not occur in Malaya. However it is probably realistic to assume that the PMP storms will cause rainfall over wide areas and that the PMP will not arise from completely isolated showers.

TABLE V—SUGGESTED DEPTH–AREA RELATIONSHIPS FOR USE WITH FIGURES 2 AND 3*

Area *square miles*	Percentage of probable maximum 24-hour point rainfall
50	95
100	93
200	90
400	86

*Based on U.S. Weather Bureau hurricane model and assuming rainfall duration from 12–24 hours.

Acknowledgements.—The rainfall data were supplied by the Director, Drainage and Irrigation Department, Kuala Lumpur, Malaysia. The calculations were carried out by the Electronic Computing Laboratory, University of Leeds.

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551.509.325:551.591.36(412)

VISIBILITY IN PRECIPITATION AT KINLOSS

By S. M. ROSS

An analysis has been made of the visibility reported in various forms of precipitation at Kinloss (57° 38′N, 03° 34′W), to find if a relationship exists between the visibility and the type and intensity of precipitation which could be useful in local forecasting. In particular, it was thought that some evidence might be

obtained to justify the popular practice of forecasting the visibility in rain showers as 2, 3 or 4 nautical miles (n.miles). All the daylight hourly observations (dawn to dusk) for the five-year period 1959–63 were examined, and the results are shown in Figure 1.

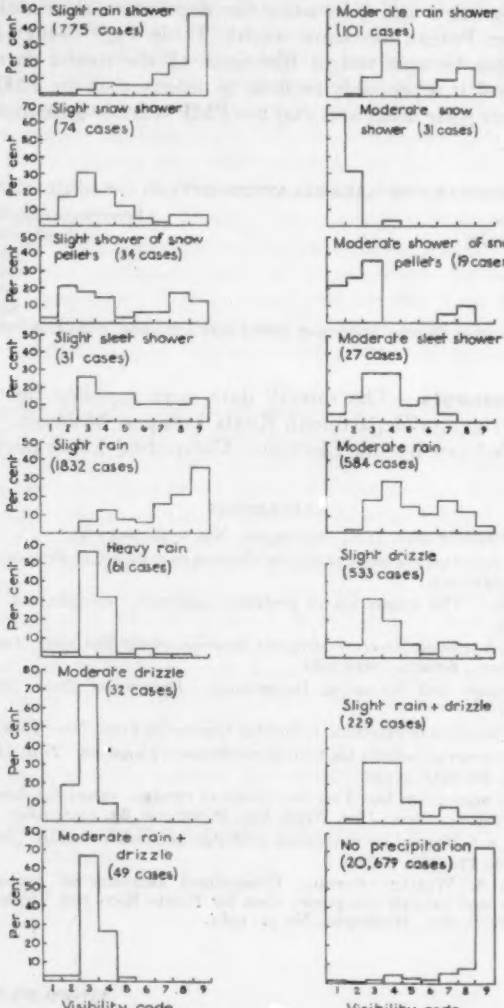

FIGURE 1—PERCENTAGE FREQUENCIES OF VISIBILITY AT KINLOSS DURING VARIOUS FORMS OF PRECIPITATION AND DURING NO PRECIPITATION

Visibility code

1— 0 to 1100 yd
2—1101 yd to 1 n.mile
3—1·1 n.miles to 2 n.miles
4—2·1 n.miles to 3 n.miles
5—3·1 n.miles to 4 n.miles
6—4·1 n.miles to 5 n.miles
7—5·1 n.miles to 6 n.miles
8—6·1 n.miles to 10 n.miles
9—over 10 n.miles

The histograms speak for themselves and show, in most cases, a fairly well-defined maximum for each type of precipitation. It should be noted that the visibility ranges used are not those of the international reporting code and that the histogram scale is not a distance scale. The reported visibility in a shower is less likely to give a true measure of the reduction in visibility, because of the limited horizontal extent of the precipitation. However, from the histograms there would appear to be grounds for forecasting visibilities of 8 n.miles in slight rain and slight rain showers, 2·5 n.miles in moderate rain and moderate rain showers, and 1·5 n.miles in drizzle, rain and drizzle, and heavy rain.

Some difficulty may arise in classifying the type of precipitation. For example, 'drizzly showers' occur over the sea and in coastal areas under conditions where a thick sheet of stratocumulus forms under a strong inversion at low level, say 5500 feet, with the temperature at the top of the cloud well below 0°C. The cloud occasionally shows cumuliform appearance but the precipitation from it takes the form of rain and drizzle rather than showers, and with convergence or coastal uplift, the precipitation may be very persistent. When the cloud is cumuliform, the precipitation is often classified as a shower, but the poor visibility associated with it is typical of rain and drizzle.

Jefferson* has produced histograms of a similar kind. He used the ranges in the international visibility code, and compared the visibility frequencies in various forms of precipitation at five ocean weather stations (taken as being smoke-free areas) with those at Manchester Airport (typical of a smoke-polluted area). In Figure 2, the Kinloss visibility frequencies are compared with those from the ocean weather stations—both sets having been reduced to a common scale, which differs from that used in Figure 1. As the Kinloss observations are for all daylight hours, a number of occasions may be included where visibility was reduced under morning or evening inversions. In spite of this, one would expect agreement in the visibilities in such smoke-free localities, but the reported visibilities tend to be poorer at Kinloss than at the ocean weather stations in slight rain showers, slight rain and slight drizzle; this tendency becomes stronger in the moderate forms of these types of precipitation; in showers of sleet or snow, poor visibilities are much more common at Kinloss than at the ocean weather stations.

Jefferson also refers to the work of Poljakova and Tret'jakov on visibility in precipitation. Here a visibility of 2·7 n.miles is given as the calculated value at the upper limit of moderate rain (4 millimetres per hour) and, from the graph relating visibility and rate of snowfall, a visibility of approximately 1 n.mile is shown at the point where the intensity of snowfall changes from slight to moderate. The reported visibilities at Kinloss are very much closer to these than are those at the ocean weather stations. For moderate snow showers at Kinloss Figure 2 shows only 3 per cent (one shower) with visibility greater than 1 n.mile, while at the ocean weather stations, visibilities greater than 1 n.mile are shown for some 90 per cent of the 71 showers observed. The Kinloss figures are closer to Jefferson's figures for Manchester Airport than to those for the weather stations, in spite of Manchester being an area with smoke pollution.

At smoke-free stations such as Kinloss, an assessment can be made of the visibility appropriate to the type and intensity of precipitation. In industrial

*JEFFERSON, G. J.; Visibility in precipitation. *Met. Mag., London*, 90, 1961, p.168.

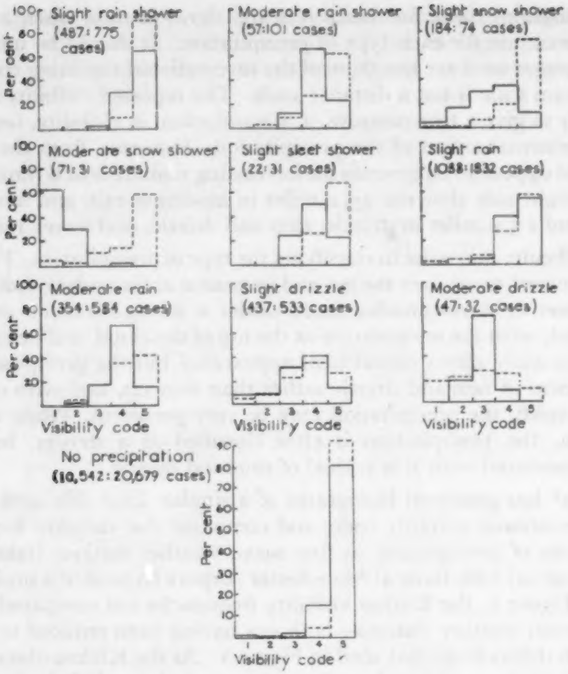

FIGURE 2—COMPARISON OF THE PERCENTAGE FREQUENCIES OF VISIBILITY AT KINLOSS WITH THOSE AT OCEAN WEATHER STATIONS A, C, J, I AND M DURING VARIOUS FORMS OF PRECIPITATION AND DURING NO PRECIPITATION

——— Kinloss (1959–63)

— — — Ocean weather stations (Jefferson investigation, approximately 1953–59)

Visibility code

1— 0 to 1100 yd
2—1101 yd to 1 n.mile
3—1·1 n.miles to 2 n.miles
4—2·1 n.miles to 6 n.miles
5—over 6 n.miles

In the 'number of cases' the first figure is for the ocean weather stations and the second figure is for Kinloss.

areas the haze may be thick enough at times to obscure the effects of precipitation on visibility, and much weight has to be put on local knowledge of smoke sources. At sea, with featureless surroundings and a horizon only some 6 n.miles distant, observers must have great difficulty in estimating visibility. Furthermore when making estimates of precipitation intensity, they do not have the assistance of a rain record, as may be available for land observers. No way presents itself of checking these reports subsequently, nor can they be compared directly with those from land stations. However, whatever the difficulties, the problem remains that these differences between land-based and sea-based estimates are appreciable.

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A PRELIMINARY STUDY OF THE OCCURRENCE OF ICE CRYSTALS IN LAYER CLOUDS

By J. B. STEWART

Summary.—Flights have been made to investigate the occurrence of ice crystals in layer clouds, using an icing rod to collect samples of the cloud particles—concentrations down to one ice crystal per cubic metre can be detected by this method. From a study of 26 layers of cloud, it has been found that ice crystals can occur in stratocumulus cloud, whose lowest temperature is only −7°C, and also that some altocumulus clouds with temperatures below −20°C contained only supercooled water drops.

Introduction.—It is now generally accepted that precipitation can form by either the Bergeron or the coalescence process, but information on the relative importance of the two processes is sparse, particularly for layer clouds. Theoretical calculations have shown that initially the Bergeron process is more efficient, and therefore it is possible in certain circumstances for precipitation to form by this process, when none would form by the coalescence process. Since the Bergeron process begins to operate as soon as there are ice crystals as well as supercooled water drops in the cloud, it is only necessary to be able to estimate the probability of clouds at a particular temperature containing ice crystals to be able to infer the importance of the Bergeron process in precipitation formation, although there is still some doubt concerning the necessary concentration of ice crystals. The occurrence of ice crystals in natural clouds can be either observed directly or inferred from measurements of the concentration of ice-forming nuclei. Few direct investigations of cloud composition have been made because of the difficulties and expense which are involved. The direct observations, most of which were made in convective clouds, have been reviewed by Mossop,[1] who concludes that it appears, in general, that ice formation in clouds only becomes frequent at temperatures below −12°C. It is shown in the work described here that ice crystals can be formed quite frequently at temperatures above −10°C in layer clouds.

Methods used to detect ice crystals.—For this preliminary study, it was decided to confine the investigation to the development and use of methods, which could detect whether or not ice crystals were present in the cloud, but did not measure their concentration. To be able to measure the concentration would have required the design and construction of elaborate equipment, which would have entailed a long delay, whereas the apparatus used to detect ice crystals was already available. Also these methods had the added advantage of simplicity, which is very important when the work has to be carried out under the difficult conditions experienced in aircraft. Unfortunately the methods used require the aircraft to be flying through cloud for a few minutes, therefore the investigation had to be restricted to layer clouds—the aircraft would take ten seconds or less to fly through the top of a cumulus cloud. However, by restricting the investigation to layer clouds, there are the further advantages that much more accurate measurements of the lowest temperature at which the ice crystals formed can be made and large volumes of the cloud can be sampled.

The simplest method available is the visual detection of the ice crystals. Ice crystals reflect much more light than supercooled water drops and therefore the former can be distinguished easily from the water drops as the cloud passes the aircraft. To enhance the contrast between the ice crystals and the water

drops, the cloud particles were viewed against a dark background, which was provided by extending a blackened icing rod out into the airstream from the side of the aircraft.

To confirm the visual observations, the blackened rod was also used to collect some of the cloud particles. By inspecting the sample after the rod had been withdrawn into the aircraft, it was easy to determine the composition of the cloud. If the sample on the rod only consisted of clear ice, this showed that the cloud was composed only of supercooled water drops, whereas if the ice sample contained white smudges these showed that there were also ice crystals present in the cloud. The ice crystals were readily visible in the clear ice, because ice crystals in clouds of mixed composition rapidly grow large. If there was no icing-up of the rod, but perhaps a few ice crystals stuck to it, this suggested that there were no supercooled water drops in the cloud, and that the cloud contained only ice crystals—this was confirmed by the visual appearance of the cloud. The dimensions of the icing rod were 0·6 cm diameter by about 25 cm long and the aircraft was flown at 60 to 80 m/s, so the volume of air through which the rod passed was about 6 m^3 per minute. The length of time that the rod was exposed depended on the rate of icing ; usually one to two millimetres of ice were allowed to accrete and this took a few minutes. Therefore, even allowing for an efficiency of catch of less than unity, the minimum detectable concentration was better than one ice crystal per cubic metre.

Flight procedure.—Flights were made when the forecast suggested that a discrete layer or layers of cloud with little or no upper cloud could be expected. When the aircraft reached a suitable layer of cloud, the following measurements and observations were made : the lowest temperature in the cloud, the cloud height and its thickness, the presence of any ice crystals in the cloud and the height of any upper cloud. On a typical flight the aircraft would descend to 200 m below the cloud and then climb slowly at less than 200 m per minute—until a height of about 500 m above the cloud top was reached, taking temperatures every half minute and also exposing the black rod while the aircraft was in cloud. If there was any upper cloud present, then the ascent was continued until the upper cloud was reached and its height above the lower layer could be measured. Temperatures were again measured on the descent to below the layer of cloud ; further runs would then be made in cloud with the icing rod exposed for a few minutes at a time and then retracted for the ice sample to be inspected. This flight pattern would be repeated for other layers of cloud or for other parts of the same layer.

Results.—Between 1961 and 1966 inclusive, 39 flights were carried out in the Hastings and Varsity aircraft of the Meteorological Research Flight to investigate the occurrence of ice crystals in natural clouds. On 16 of these flights observations were successfully made in layers of cloud, which could not have been seeded from above, because either there was no upper cloud, or the upper cloud was so high that any ice crystals falling from it would completely evaporate before reaching the lower cloud. On these 16 flights, 26 separate layers of cloud were studied. Of these clouds, 2 were cirrus, 10 were altocumulus, 1 was altostratus and the rest were classed as stratocumulus. A summary of the flights and the cloud observations is given in Table I. In those cases where the clouds varied in thickness, temperature or composition, more than one set of measurements for a single layer is included (this is indicated by the

TABLE I—OBSERVATIONS OF ICE CRYSTALS IN LAYER CLOUDS

Date	Times Take-off (GMT)	Times Landing (GMT)	Cloud type	Time (GMT)	Approximate position	Heights Base (metres)	Heights Top (metres)	Thickness (metres)	Lowest temp. (°C)	Composition	Upper cloud	Remarks
4. 3.63	1030	1240	Ac len	1100	Farnborough	5330	5420	90	–19	Only water drops	None	Small wave clouds
			Ac len	1130	Farnborough	5490	5640	150	–21	Only water drops	None	Small wave clouds
7. 5.63	1053	1226	Ac	1130	East Anglia	3510	3660	150	–12	Only water drops	None	Extensive layer
				1140	East Anglia	3570	3630	60	–11	Only water drops	None	
27.11.63	1040	1311	Ac len	1140	53°N 3°E	4880	4910	30	–24	Only ice crystals	None	Small patches of cloud
			Ac len	1150	53°N 2½° E	5210	5240	30	–27	Only ice crystals	None	Small patches of cloud
			Ac len	1200	53°N 2°E	5490	5520	30	–28	Only ice crystals	None	Small patches of cloud
9.12.63	1035	1225	Sc	1100	Farnborough	610	760	150	–3	Only water drops	None	Extensive, uniform layer
10.12.63	1102	1212	Sc	1130	Farnborough	820	1090	270	–6	Only water drops	None	Extensive, uniform layer
11.12.63	1400	1515	As	1430	Farnborough	2440	4420	1980	–14	Only water drops	Few streaks of Ci	Extensive layer
28. 1.64	1010	1210	Sc	1025	Bedford	1680	1980	300	–8	Only water drops	None	Broken cloud
			Cs	1110	53°N 2°E	N/A	7460	—	–44	Only ice crystals	None	First cold front
			Cs	1140	Marham	N/A	6550	—	–40	Only ice crystals	None	Second cold front
11. 2.64	1039	1235	Sc	1110	Pershore	2410	2590	180	–11	Only water drops	No cloud between 2.6 and 6.0 km	Extensive, uniform layer
			Ac len	1150	Pershore	5580	5610	30	–26	Only water drops	Some Ci streaks	Small patches of cloud
19. 2.64	1020	1255	Sc	1040	Bedford	N/A	1310	—	–9	Only water drops	None	Extensive layer
				1130	53°N 2°E	1220	1370	150	–10	Only water drops	None	
				1200	Marham	980	1280	300	–9	Mixed	None	
				1220	Bedford	760	1250	490	–9	Only water drops	None	
20. 2.64	1007	1140	Sc	1030	Boscombe Down	610	850	240	–7	Mixed	None	Extensive layer
				1040	Boscombe Down	700	970	270	–8	Mixed	None	
				1100	Boscombe Down	700	970	270	–9	Only water drops	None	
3. 3.64	1010	1110	Sc	1030	Farnborough	1680	1740	60	–7	Only water drops	None	Broken cloud
				1045	Farnborough	1520	1610	90	–6	Only water drops	None	
25. 3.64	0926	1115	Ac	0950	Boscombe Down	4720	5020	300	–24	Mixed	None	Extensive layer
31. 3.64	1342	1520	Sc	1415	Bedford	1070	1800	730	–8	Only water drops	None	
			Sc	1450	Marham	1190	1370	180	–6	Only water drops	None	
17. 6.64	1323	1540	Ac len	1440	Central Wales	5670	5730	60	–21	Only water drops	Ci about 40 km to east	Small patches of cloud
			Ac len	1450	Central Wales	6040	6100	60	–24	Only water drops	Ci about 40 km to east	Small patches of cloud
26. 2.65	1005	1130	Sc	1030	Benson	1590	1740	150	–11	Mixed	Ac to north	Extensive layer
			Sc cugen	1100	Benson	910	1520–1670	610–760	–11	Mixed	Ac to north	Broken cloud
13. 4.66	1248	1605	Sc	1250	Farnborough	550	1280	730	–5	Only water drops	Ci about 100 km to south and west	Extensive layer
				1600	Farnborough	910	1310	400	–6	Only water drops	None	
			Sc	1315	Bedford	1370	1520	150	–8	Only water drops	None	Broken layer with Cu fra beneath
				1520	Bedford	910	1610	700	–9	Mixed	None	Extensive layer
			Sc	1400	Marham	1070	1740	670	–11	Mixed	None	Extensive layer with a few breaks in it
				1430	53°N 2°E	850	1860	1010	–12	Mixed	None	

bracketing), whereas generally only one set of measurements is given, even though a number of runs were made through the cloud. The original measurements of height were made in feet, but they have been converted into metres for this paper.

As can be seen from the table, of the clouds examined, half were stratocumulus, which had temperatures ranging from $-3°$ to $-12°C$. In 5 of the 13 stratocumulus layers ice crystals were found at temperatures between $-7°$ and $-12°C$. In complete contrast it was found that out of 8 altocumulus lenticularis clouds 5 contained only supercooled water drops, even though the cloud temperatures were as low as $-19°$ to $-26°C$. Before being shown in the form of a histogram (Figure 1), the observations were divided into two groups, on the basis of the probable life-times of the cloud drops, because it has been shown that the probability of freezing is a function of time (Bigg,[2] Mossop[1]). It can be readily calculated that the life-times of the drops in wave clouds will be less than 10 minutes and probably less than 5 minutes, whereas for the drops in extensive layer clouds the life-times will be of the order of tens of minutes, and therefore it is to be expected that ice crystals should first occur in wave clouds at lower temperatures than in extensive layer clouds.

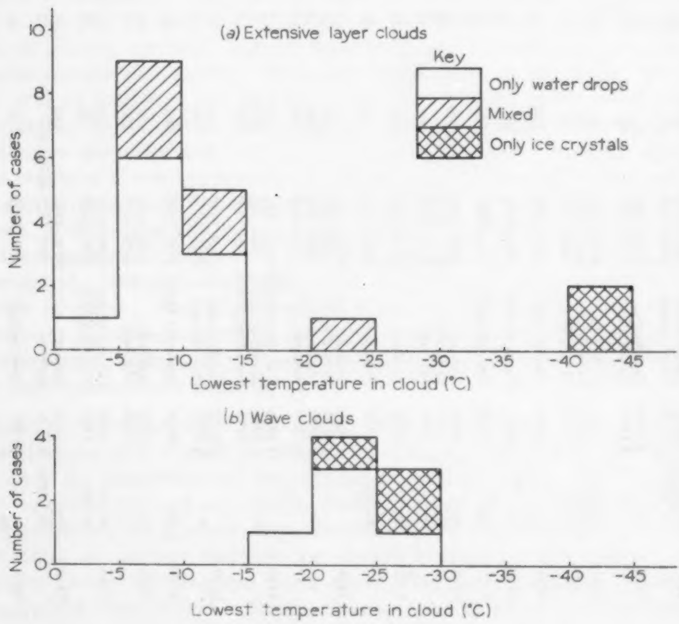

FIGURE 1—THE COMPOSITION OF LAYER CLOUDS AS A FUNCTION OF THEIR TEMPERATURES

From these limited observations of the composition of layer clouds, it seems that ice crystals can form at temperatures above −10°C in extensive layer clouds, where the drops have long life-times, but in wave clouds (where the drops have very short life-times) ice crystals only form at much lower temperatures. This is in general agreement with the conclusion reached by Mossop that ice crystals occur frequently only at temperatures below −12°C. This conclusion was based mainly on studies of convective clouds, in which the drops would have had shorter life-times than those in extensive clouds and therefore it would be expected that the ice crystals would first occur in convective clouds at lower temperatures than in the extensive layer clouds.

Acknowledgements.—I am particularly indebted to the RAF aircrew and the staff of the Meteorological Research Flight for their help with the flights.

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1. MOSSOP, S. C. ; Atmospheric ice nuclei. *Z. angew. Math. Phys., Basel,* **14,** 1963, p.456.
2. BIGG, E. K. : The formation of atmospheric ice crystals by the freezing of droplets. *Q. Jnl R. met. Soc., London,* **79,** 1953, p.510.

REVIEWS

Physics of the atmosphere—a course in meteorology, by P. N. Tverskoi. 9½in × 7in, pp. xi + 561, *illus.* (translated from the Russian by the Israel Program for Scientific Translations, Jerusalem), Oldbourne Press, 1–5 Portpool Lane, London EC1, 1965. Price : £8 13*s*.

We have here the translation of a Russian textbook which is approved by the Ministry of Higher and Secondary Specialized Education of the U.S.S.R. as a textbook for hydrometeorological institutes and universities. It is also meant to serve as a manual for workers in the field.

It is clear from the contents that the book is not intended to cover all the aspects of meteorology that a student at a university may be expected to study and a good deal of supplementary material, covered no doubt in Russia by other texts, would be needed to give a rounded course. It is of great interest to see what kind of material receives official blessing as suitable for a standard textbook but we cannot taste the style of the original in this translation. It would also be interesting to know who approves of such a text—perhaps a body of meteorologists ?

There can be little doubt that the text covers the physics of the atmosphere in a thorough way and that the material is up to date, perhaps sometimes too recent to have withstood criticism and passed into the body of knowledge. There must inevitably be some irritation with a text which does not document the more recent work, bearing in mind that it is meant to serve workers in the field as well as students. The book is divided into eight parts and deals with almost all branches of the physics of the atmosphere, including optical, electrical and acoustic phenomena. The major portion of the book is, however, sensibly devoted to pressure, temperature and moisture in the atmosphere, with a short chapter on atmospheric motion, which no doubt is amplified in some other official text. The material is well chosen and probably more complete than in similar western texts. One never feels that the wealth of material is presented solely for the sake of completeness but that the pattern of each of these chapters

has been well chosen and then faithfully followed. The author had, as he acknowledges, the aid of other well-known experts, for example Kondratiev and Yudin who doubtless made many suggestions about the form of the parts dealing with radiation and atmospheric motions. There is a natural emphasis in the references to more recent work on the contributions from Russian authors, which is welcome in bringing them to our attention.

The illustrations are not up to the standard that we expect. The cloud photographs are very poor, as are the other photographs, and some of the line diagrams are far from clear. The translation is occasionally obscure and once or twice positively misleading. I felt the lack of an index in a book which is intended for practical workers, especially as the list of contents is not particularly exhaustive. The price of the book puts it outside the pocket of a young student but most meteorological libraries will need to have a copy available for use.

E. KNIGHTING

Meteorology, by A. Miller. 9in × 6in, pp. vii + 128, *illus.*, C. E. Merrill Books, Inc., Columbus, Ohio, 1966. Price : Paper 14*s*, Cloth 32*s*.

This book is one of a series, the Physical Science Series, devised by the publishers to provide integrated interdisciplinary courses for the scientific education of non-science students in American colleges and universities. It is a textbook written in an attractive yet authoritative style. There are five chapters, namely, The Atmosphere, The Atmosphere's Energy, Air in Motion, Weather Forecasting, and Climate, followed by appendices specifying units used, psychometric tables, 'standard' atmosphere, plotting models and bibliography. Each chapter is followed by some four to seven problems. There is also an adequate index.

The first chapter is an orthodox presentation of the properties of the atmosphere and the observations made, including temperature, pressure, humidity, clouds and precipitation, wind and upper air observations. One of the problems is 'Make a list of at least a dozen ways in which the atmosphere—its constituents and its motions—affect man and his activities.' The second chapter deals with the atmosphere as a heat engine, solar energy, the earth's heat balance, the distribution of heat energy over the earth and the temperature lag. The diagram illustrating the earth's heat balance could have been made clearer and more effective. Problem 'Compute the total energy per minute intercepted by the earth and the fraction of the total solar energy output this represents.' Chapter 3, dealing with Air in Motion, is very good, the treatment of Coriolis force, often a weak point, being very effective. There is a mistake in Figure 3·25(*a*) showing a warm-front type occlusion. It is good to see satellite photographs reproduced but much better ones are available than those shown. A notable and welcome feature of this chapter is the attention given to the subject of Scales of Motion. 'Weather Forecasting' describes orthodox subjective techniques, numerical prediction and extended and long-range forecasts. Problem 'Is the complexity of the frontal analyses on the sea-level charts greater over the oceans or over the continents ? Why should there be a difference ?' The chapter on Climate contains a section on weather modification which gives the facts soberly and concludes with the words 'The

question of weather control is a very important one and deserves serious consideration. But until the atmospheric scientist understands atmospheric process more fully and therefore the possible effects that his tinkering may have, he must proceed cautiously. After all, man is very delicately tuned to his existing environment.'

The layout of the book is good and the cover photograph is most attractive and intriguing. A defect in the paper-back edition is the lack of opacity of the paper which permits diagrams and prints to show through from the underside of the page. This book can be recommended for use in schools and colleges and for the instruction of the intelligent layman.

T. H. KIRK

Grundlagen der Meteorologie für Landwirtschaft Gartenbau und Forstwirtschaft, by W. Hesse. 9¼in × 6¾in, pp. 568 *illus.*, Akademische Verlagsgesellschaft, Geest & Portig K.-G., Leipzig 1966, Price: DM 63.

The title of this book can be translated as 'Fundamentals of meteorology for agriculture, horticulture and forestry'. In his foreword, Professor Hesse emphasizes the importance of weather and climate on these activities. He states that his book is intended to recognize the value of agrometeorology and to fill a gap in the specialist literature, and that it contains the fundamentals of meteorology and climatology in relation to their use in agriculture, horticulture and forestry. This leads one to expect a book with a considerable emphasis on agrometeorology, although this expectation is somewhat dampened by a later sentence in the foreword stating that the author does not claim the book to be a special agrometeorological work. In fact, the emphasis is on the fundamentals of meteorology and there are not more than occasional references to the agricultural aspects. To those with particular interests in agrometeorology the book is inevitably somewhat disappointing and the title distinctly misleading.

The first four chapters deal with the subdivisions and history of meteorology and with the atmosphere in general, including such topics as its composition, electrical and optical properties, and radioactivity. There follows a chapter on radiation where some mention is made of measurements of the radiation balance over crops. The next eight chapters deal mainly with the individual meteorological elements ; in general, a discussion of the element is followed by methods of measurement or estimation and then by maps, tables or graphs. The section on soil moisture and the chapter on evaporation are of particular interest in agrometeorology, but it is disappointing that the Piché evaporimeter receives as much attention as the work of Penman.

Synoptic meteorology and forecasting occupy the next nine chapters, starting with the organization of the synoptic service and including such topics as air masses, fronts, cyclones and anticyclones. The remaining seven chapters are concerned with various aspects of climatology, such as climatic types and classification, and the variation of climate. Chapter 26 deals with scales of climate which can be distinguished i.e., macro-, meso- and micro-climate and soil climate. These are of considerable interest to agrometeorologists and these 20 pages are by far the largest portion of the book which lives up to its title. Granted that a knowledge of a general meteorology is necessary for a specialist in agrometeorology, it seems difficult to justify the inclusion of some of the

material in this book. Among the many examples which could be mentioned are Table 4, giving the different characteristics of Los Angeles and London smog ; Figure 78, showing the types of tropopause ; and much of chapters 14 and 15 dealing with the organization of the synoptic service and the methods of synoptic aerology. On the other hand, the descriptions and photographs of many of the meteorological instruments will be valuable to agrometeorologists. Some of these, e.g. the kata-thermometer and the neutron scatterer, are not often mentioned in meteorological textbooks.

The treatment of the subject matter throughout is descriptive rather than mathematical and in this respect the book may be said to cater for agricultural interests. The book is excellently produced and almost without exception the large number of text figures are models of clarity, whether they are line diagrams or photographs. There is a substantial bibliography, subdivided by chapters, and adequate author and subject indexes are given.

W. H. HOGG

Applied climatology—an introduction, by J. F. Griffiths. 10in × 7½in, pp. x + 118, *illus.*, Oxford University Press, Ely House, 37 Dover Street, London W1, 1966. Price : 30*s*.

Within the meteorological literature a considerable gap exists in the field of applied climatology. Although numerous papers exist, often highly technical, on particular applications of climatology, few attempts have so far been made to collate these in a form suitable for the non-specialist. Probably the most notable works along these lines published in the past have been those of C. E. P. Brooks, in particular his 'Climate in everyday life'.*

The present book, written by the Assistant Professor of Meteorology at the Texas Agricultural and Mechanical University, goes more than a little way towards remedying the paucity of meteorological literature in this field. It is rightly termed 'an introduction' however, touching as it does on almost every conceivable aspect of applied climatology in only a little over a hundred pages.

The first eight chapters deal with the basic elements of climatology, including the making of observations, an account of Köppen's climatic classification and tables of monthly rainfall and temperature for over a hundred stations representative of different climates throughout the world. The condensed form of some of these early chapters can be judged from the fact that ocean currents, the general circulation, air masses, fronts and meso-scale disturbances are all dealt with in three pages of text, two maps and one diagram. Compression of material is of course to some extent unavoidable in an introductory work of this nature, but it is unfortunate that it sometimes leads to rather woolly explanations such as 'due to the change of air masses associated with the passage of a front there is usually some form of precipitation noticed at this time' (Chapter 4) especially as the author wastes words in some other places, e.g. by describing the eye as the 'organ of vision' (Chapter 2).

The remaining nine chapters deal with the relationships of climatology to soils, vegetation, agriculture, forestry, humans, animals, buildings, hydrology,

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*BROOKS, C. E. P.; Climate in everyday life. London, Ernest Benn Ltd, 1950.

industry, communications and transport. On the whole these chapters are interesting and useful, and whet the appetite for further exploration of many of the topics covered. The author might well have referred the reader to the standard meteorological and climatological textbooks for many of the subjects dealt with in the first part of the book and expanded these later chapters which in the reviewer's opinion are the more valuable ones. For example, the chapter on hydrology, which in its present form only occupies five pages, could well have been enlarged to make it both more useful and more readily intelligible to the non-specialist.

Professor Griffiths, although now teaching in America, is of British origin and has served with the East African Meteorological Department so that his book has a refreshingly cosmopolitan flavour. However, it is surprising to find very few references in it to British work in the field of agricultural meteorology, e.g. that of L. P. Smith and his colleagues.

The presentation of material is of a high standard, although a sprinkling of minor misprints was noted. The printing is clear, as are the line drawings and maps which illustrate the text and the author commendably uses decimal notation for numbering chapters and paragraphs. There are a large number of references usefully listed under chapter headings at the end of the book, together with a comprehensive index. A glossary of units and unfamiliar terms used (not all of which are defined in the text) would have been a helpful addition to the book which otherwise is readily understandable to the non-specialist except in the few instances referred to resulting from excessive condensation of the material.

Whilst not entirely successful, this is nevertheless a valuable and not too technical book which will be a stimulation to further reading and investigations in the rapidly expanding and increasingly important field of applied climatology and could be read with profit by both users and dispensers of climatological data.

P. M. STEPHENSON

OBITUARY

We regret to record the death of Mr W. J. Cormack, SXO, London (Heathrow) Airport on 30 September 1966.

NOTES AND NEWS

India Meteorological Department

Official notification has been received that Dr L. S. Mathur has succeeded Mr C. Ramaswamy as Director-General of Observations, India Meteorological Department, as from 20 August 1966.

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